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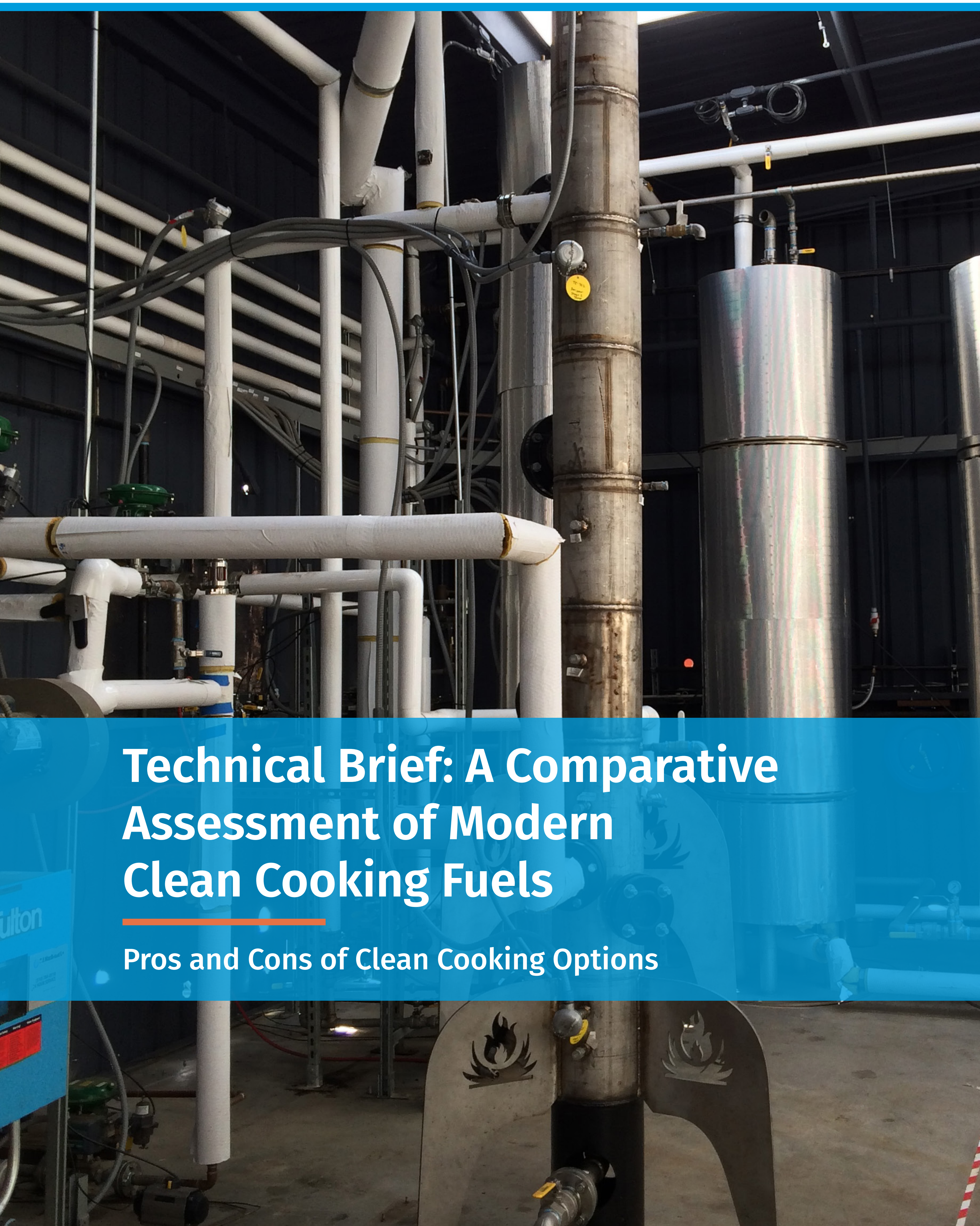

# Technical Brief: A Comparative Assessment of Modern Clean Cooking Fuels

## Pros and Cons of Clean Cooking Options

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UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

COUNCIL ON
ETHANOL
CLEAN COOKING

# Background

Globally, over

**2.1 billion people**

lack access to clean cooking fuels and technologies. Traditional stoves and open fires are still used by

**one in three people**

in the poorest regions of the world. These have adverse social, economic, and environmental consequences. The inhalation of hazardous smoke every day has led to millions of premature deaths each year. Vulnerable social groups such as women and children are disproportionately affected since they spend hours each day collecting and foraging for firewood to burn. The time spent gathering fuel and tending to fire has contributed to time poverty and restricted women's and children's opportunities to pursue basic education and formal employment. In Sub-Saharan Africa, households that lack access to clean cooking spend an average of two hours per day collecting fuel and an additional three hours cooking and preparing food. This limits people, especially women, on whom the burden typically falls, from attaining financial autonomy.

The cost of not having access to clean cooking has adverse effects on women, health, the environment, and productivity. The incomplete combustion of solid biomass in a three-stone fire produces significant particulate matter, which results in household air pollution and contributes to around

**3.7 million fatalities**

per year globally. Women and children are the most exposed, making it the third-largest cause of premature deaths among these groups globally and the second-largest contributor in Sub-Saharan Africa. Traditional cooking methods also increase greenhouse gas emissions through incomplete combustion, which releases methane and other particles. The cutting down of trees for fuelwood and charcoal production causes deforestation and environmental degradation.[1]

The collection of firewood for cooking can expose women to gender-based violence as they often have to leave their communities and travel long distances in search of wood. This not only puts them at risk of abuse but also limits their opportunities for education and entrepreneurship. Collecting and carrying firewood can also be physically burdensome, with some communities needing up to 10 kg or more of firewood per day for traditional cookstoves. The time spent on these activities also prevents women from starting a business or attending school, making it harder for them to attain financial autonomy. Exposure to indoor air pollution is a serious concern for children's development. It leads to respiratory conditions that last into adulthood. Exposure to household air pollution causes more than 40 per cent of all pneumonia deaths in children under the age of five.[2]

1 https://iea.blob.core.windows.net/assets/75f59c60-c383-48ea-a3be-943a964232a0/AVisionforCleanCookingAccessforAll.pdf.

2 https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health.

The 2023 Tracking SDG7 Report states that around **1.9 billion people** will still be without access to clean cooking in 2030 if current trends continue. Moreover, six out of ten people without access to clean cooking in 2030 will be in Sub-Saharan Africa.[3] With the timeline for achieving the Sustainable Development Goals (SDGs) closely approaching its end, this calls for urgent action to increase momentum towards switching to clean cooking.

## The Alternatives

A shift from conventional sources of energy for cooking raises the question of what alternatives exist. Cooking is an energy-intensive process, so the transition needs to be to sources that can meet the energy demand, are environmentally sound, modern in terms of customer experience, positive from a socioeconomic perspective, and efficient. A range of fuels have been considered and evaluated:

**Improved biomass stoves** are enclosed stoves that burn solid fuels in a more efficient manner. The heat is prevented from escaping, and the combustion process is improved compared to traditional cooking stoves. Higher efficiency is attained through better combustion of the fuel, maximum transfer of heat produced in the combustion from the flame and hot gases to the cooking pot, and minimising the loss of heat to the surroundings.

**Biogas** is produced through the breaking down of organic matter in an anaerobic (oxygen-free) environment. It is composed of approximately 55 per cent methane, 45 per cent carbon dioxide, and traces of other gases. Since the raw material for biogas production is food waste or manure, it is logical to place biogas plants in more rural and suburban areas. Despite many years of effort, technological advancements in the development of biogas have not progressed significantly. As a result, there is still considerable time and effort needed from households to feed and maintain the biogas systems.

**Natural gas** is a fossil fuel produced from the remains of plants and animals. The largest component of natural gas is methane. The infrastructure for natural gas includes a piping system that delivers the gas to households. In the cities of developing countries seeking an alternative fuel, there is a low household density, and the gas would be used for cooking only. Due to this, the business models for infrastructure investment in these regions are rather weak. Furthermore, natural gas is also not a renewable fuel.

[3] https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2023-full_report.pdf.

**Liquefied petroleum gas (LPG)** is a fuel that mainly consists of propane and butane and is distributed in large pressurised cylinders. As per the International Energy Agency (IEA), in the Access for All scenarios 2022-2030, LPG would contribute 44 per cent of the energy technology mix. In the last decade, 70 per cent of those who gained access did so through LPG.[4] However, LPG is a non-renewable fuel as it is produced as a by-product of the oil and gas sector. Furthermore, it is an imported fuel in many developing countries, and there is minimal local economic impact. For most developing countries, this also means a dependence on fluctuating prices and currency values.

**Electric cooking** is considered by the IEA to be a major player in the transition to clean cooking, along with LPG. However, enabling this requires upgraded local distribution grids and increased reliability of household connections. Shifting to electric cooking places a major strain on the electric grid, and this will require major grid and generation investments.[5]

**Bioethanol** is a fully renewable alternative that consists of a simple burner attached to a small canister containing alcohol fuel. The fuel is made from crops such as corn or sugar that have been fermented and distilled. In contrast to some other fuels, ethanol can be produced locally, creating an opportunity for in-country production and avoiding the risks of price fluctuations and supply shortages. Importantly, the IEA has come out in support of ethanol as a viable modern liquid fuel for use in clean cooking across Africa.[6]

Given the context and alternative cooking fuels stated above, *LPG, electric cooking and ethanol are the feasible options that can be rapidly delivered on a significant scale*. This paper aims to investigate the three fuel sources to determine the most suitable alternative when advocating for clean cooking.

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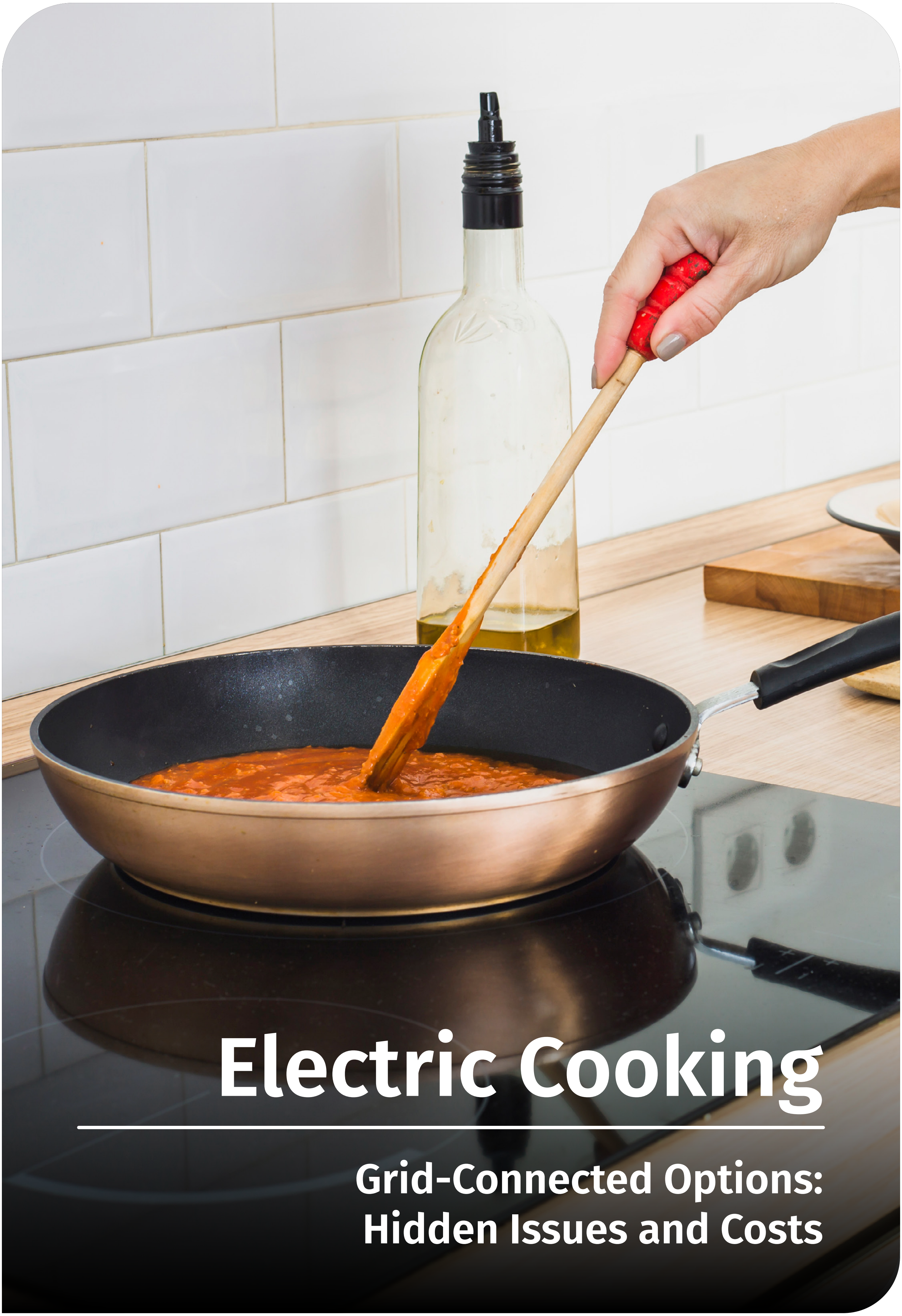
4 https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all/executive-summary.

5 https://iea.blob.core.windows.net/assets/75f59c60-c383-48ea-a3be-943a964232a0/AVisionforCleanCookingAccessforAll.pdf.

6 IEA (2022). Africa Energy Outlook 2022. Paris: International Energy Agency.



# Electric Cooking

## Grid-Connected Options: Hidden Issues and Costs

Motivations and arguments for electricity as an energy source for clean cooking have expanded over the past few years. A strong case can be made for so-called eCooking (or electric cooking) from a household perspective, including:[7]


- Virtually zero indoor air pollution.
- Highly efficient final-stage heat transfer from electrical energy into cooked food via pressure cookers and induction hobs.
- Growing levels of household grid connectivity in developing countries.
- Modern cooking techniques, such as programmable timing.

This shift is founded on the premise that the growing use of solar- and wind-based generation will enable a fully renewable clean cooking solution. However, while much has been written about household-level suitability, considerably less attention has been given to upstream electricity supply considerations.

## Slow Shift to Renewable-Based Grid Power

Yes, significant strides are being made in the shift from fossil-based power to modern renewable sources (solar and wind). However, the timeline for this transition in many countries is long. For electrical grids, the upstream sources vary greatly (coal, natural gas, nuclear, hydroelectric, etc.) and are referred to collectively as the *energy mix*.

When calculating the energy mix, the sources must be compared on the basis of the percentage of electricity generated (GWh) and not by the installed capacity (MW), which is often quoted. Here are some examples:

7 https://mecs.org.uk/blog/the-transition-to-electric-cooking-the-community-of-practice-case-for-kenya/.

- **South Africa** – In 2024, wind and solar account for only 10-11 per cent[8] of Eskom's annual production. In other words, in South Africa—where there is already a relatively high incidence of electric cooking—renewable electricity provides less than 10 per cent, while fossil fuels account for over 90 per cent. Even in 10 years, the renewable-based portion of the mix is expected to remain below 50 per cent.
- **Tanzania –** In 2022, according to the International Renewable Energy Agency (IRENA),[9] on a GWh basis, solar energy generated using photovoltaic panels (solar PV) accounts for only 1 per cent, hydroelectric for 40 per cent, and fossil fuels for 57 per cent.

Until modern renewable-based generation (solar and wind) provides more than 75 per cent of the electricity mix (kWh), advocating a large-scale switch to grid-sourced electricity for cooking should be avoided. The risk is that countries may adopt and promote electric cooking programmes (pressure cookers, induction hobs, and even electric hotplates) without first evaluating the current composition of the energy mix and the pace of transition towards renewables.

## Compounding Error of Switching to Fossil-Based Electricity

Countries that target a switch to cooking with a fossil-based electricity mix are compounding the problem, as the overall carbon footprint ($CO_2$) and greenhouse gas impact will increase.

Fossil-based electricity generation operates at only about 35 per cent efficiency. In other words, only ~35 per cent of the energy in coal or natural gas reaches the household for use in appliances. Thus, even if a highly efficient cooking appliance is utilised, operating at greater than 95 per cent conversion efficiency, the overall efficiency, or proportion of heat transferred from coal/gas to food, would be only around 33 per cent. By contrast, if natural gas were used directly in a cooking appliance, the efficiency, or proportion of heat transferred from gas to food, would be in the 65 per cent range.

In other words, continuing to cook with natural gas directly would save roughly half the $CO_2$ emissions compared to cooking with gas-fired electricity. The situation is even worse for coal-based electricity, given its higher carbon emissions per unit of heat produced.[10]

Switching to electric cooking before modern renewables make up at least 75 per cent of the energy mix (on a kWh basis) would significantly increase the household carbon footprint.

8 Eskom 2024 Integrated Annual report.

9 IRENA Energy Profile 2022.

10 https://www.eia.gov/environment/emissions/co2_vol_mass.php.

## Scale and Cost of the Shift

Cooking is an energy-intensive process, accounting for a substantial share of household energy use. This is particularly true for poorer households, as cooked food is a daily necessity and there are fewer other energy-based activities.

To assume that all kitchens will shift to electric cooking within the next 10-20 years is highly unrealistic, given the sheer scale of the transition. This would equate to converting around 280,000 households per working day. In addition, producing the additional electricity required would demand extraordinary investment in new power plants, as the switch to electric cooking represents a new demand on electricity supply.

**Let's use the United States as an example:**

In the United States, roughly four in ten households cook with natural gas or propane[11] (the remainder primarily use electricity). If annual cooking energy from gas/propane is about 0.25 quadrillion BTUs, that is ≈ 73,268 GWh.

Allowing for a net conversion efficiency of around 65 per cent for electric cooking compared to gas, this translates into 47,625 GWh per year. In other words, this is the additional annual volume of renewable-based electricity that would be required for a full transition to electric cooking in the United States.

Given that 1 MW of solar PV produces about 1.83 GWh per year, the required total installed capacity would be 26,024 MW of PV—along with costly storage (see next point).

The plant size would cover approximately 1,100 square kilometres, and at an estimated cost of $1.0 million per MW, the solar PV farm investment alone would exceed $26 billion (excluding storage, transition connections, and additional grid capacity).[12]

[11] https://www.eia.gov/energyexplained/use-of-energy/homes.php.

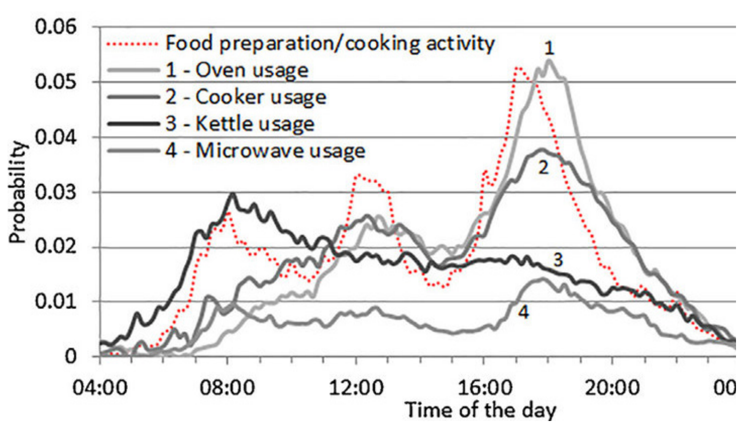
[12] EIA data.

This calculation illustrates that converting U.S. households to electric cooking would be a major undertaking. It calls into serious question the overly optimistic target of converting all households by 2045. The scale and cost of renewable electricity production required to support any nationwide electric cooking programme are massive.[13]

## Peak Growth

Perhaps the most profound issue with switching to modern renewable-based electricity (solar and wind) for cooking is the timing of when cooking is needed. Electrical is fundamentally different as a source of heat compared to all other fuels (gas, charcoal, bioethanol, etc.), in that not every kWh is equal. Each unit of electricity differs depending on where it is needed (distribution costs), the fuel/plant mix used to produce it, and—critically—the day and hour of consumption.

A key concept is the operational reality of electrical grids: supply (total power station output) must equal demand (total power required by users) throughout the year. Grid operators ensure this balance through meticulous planning and real-time dispatching of power. Failure to maintain balance leads to frequency variations and, in severe cases, grid breakdown.




[13] High-Efficiency Electric Home Rebate Program (HEEHRP), administered by the U.S. Department of Energy (DOE)

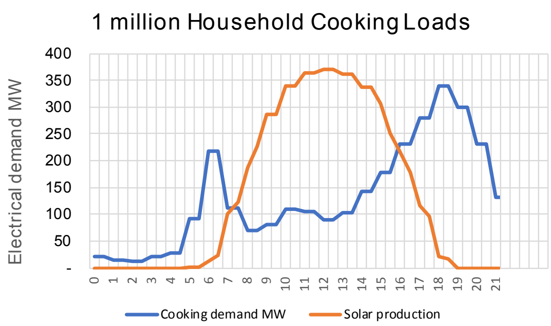
As a result, grids are highly sensitive to their overall "load profile", or the representation of user demand across hours of the day and seasons of the year. A large-scale switch to electric cooking would not only increase the total electricity demand but also significantly alter the daily demand curve. Analyses of cooking-related electricity demand show sharp peaks in the mornings and evenings, in line with typical household cooking times—far from a flat or steady load.

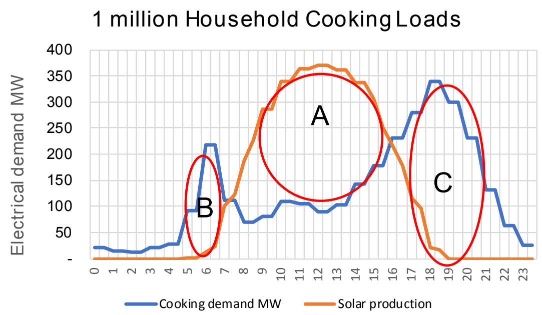
Utilities would therefore need to adjust their generation mix or add sufficient storage to accommodate these morning and evening peak loads. Unlike baseload power, such peaking plants have low utilisation rates and often rely on high-cost, high-emission fuels such as diesel. Both factors reduce the economic efficiency of adding electric cooking loads to the system.

## Renewable Production Versus Cooking Needs

Given the motivation that new renewable electricity generation can be used to support a shift to electric cooking, how do renewable load profiles compare to cooking loads?

Assuming a switch of 1 million households, each using 3 kWh/day for cooking, the power (MW) required throughout the day can be compared with a typical solar PV production profile for the same daily electricity volume. From the diagram on the left, it is clear that solar production does not coincide with cooking demand.




In the second diagram (on the right), the area marked **A** represents spare PV production that would need to be stored and then supplied during cooking demand peaks **B** and **C**. This electricity would therefore need to be stored in batteries, pumped storage, or other technologies at considerable cost.

Embarking on an electric cooking programme based on solar PV (or similarly intermittent wind power) without accounting for the cost and complexity of storage would be potentially disastrous.

## Associated Higher Renewable Electricity Costs for Cooking

Proponents of electric cooking often argue that renewable electricity is now the cheapest option. Certainly, installed solar PV costs have declined substantially to around $800/kW (including grid connection).[14] However, because approximately 50 per cent of daily solar PV production would need to be shifted to match cooking demand, this would require installing around 2.5 kWh of associated battery storage per kW of PV capacity. At present, storage costs are approximately $350/kWh.

Hence, the addition of storage would increase the overall cost of renewable investments by a factor of:

(2.5 x 350+800)/800 = 2.1 times

To advocate a shift to renewable-sourced electricity for cooking programmes based solely on the declining price of solar PV (or wind) is misleading. Once storage is factored in to ensure that electricity is available at the time of cooking demand, the effective cost of renewables increases by more than threefold.

## Worsening Grid Power Interruptions

A key point to raise is the general decline in grid reliability and the growing impact on users globally. Examples include:

- **South Africa and most neighbouring countries –** Experiencing between 4-8 hours per day of supply interruptions or load shedding due to generation difficulties. This situation has occurred intermittently for the past 10 years, with the current critical phase expected to last another 18 months.[15]
- **Pakistan –** On 23 January, the country experienced a complete grid shutdown lasting an entire day.[16] This effected 230 million people.
- **Nigeria –** The national electricity grid has collapsed more than 200 times in the past nine years, regularly resulting in widespread blackouts.[17]

Grid interruptions can result from a range of causes, including localised faults due to weather events, under-investment in distribution and transmission networks, and generation shortfalls.

Because electricity cannot be stored by households, supply outages mean that all-electric kitchens immediately face disruption, leaving households unable to cook for extended periods.

14 IRENA articles.

15 https://businesstech.co.za/news/energy/630667/south-africas-horror-year-of-load-shedding-heres-how-it-compares/.

16 https://www.outlookindia.com/international/pakistan-grid-failure-causes-major-power-outage-across-nation-news-256218.

17 https://theconversation.com/why-nigerias-electricity-grid-collapses-and-how-to-shore-it-up-179705.

## Escalating Grid Power Prices

Lastly, when considering the future price of grid electricity, it is clear that substantial increases are expected. Deregulation, privatisation, and even the transition to renewables are all contributing to higher grid power costs. Two examples illustrate this trend:

- **California –** Operating under a fully privatised grid with a considerable renewable share, the state is experiencing major price uncertainties. For example,[18] *The New York Times* has highlighted the ongoing debate on the impacts of electricity deregulation, noting that "some experts blame deregulation" for high electricity prices, and that "states that have deregulated all or parts of their electricity systems tend to have higher tariff rates."
- **France –** The national energy regulator (CRE)[19] calculated a required increase in the retail price of electricity of 108 per cent from February 2023. Although the Government intervened to cap the increase at 15 per cent, this demonstrates the magnitude of potential price hikes.

*Shifting households to electricity as the primary cooking fuel will therefore expose them directly to these escalating electricity costs.*

## Non-Grid (Decentralized) Solar PV-Based Electric Cooking: Hidden Issues and Costs

Having addressed grid-connected households, we now turn to those with no or limited grid access. For these households, solar PV systems have been proposed, comprising PV panels as the energy source, coupled with electric pressure cookers and induction hobs. In this model, expensive inverters are excluded through a direct DC connection between panel and appliance.

18 https://energyathaas.wordpress.com/2023/01/17/more-breaking-news-california-electricity-prices-are-still-high/.

19 https://www.euractiv.com/section/electricity/news/french-consumers-shielded-from-proposed-doubling-of-electricity-prices/.

For both, induction and pressure cooker applications, however, the power of the appliances has been significantly lowered to around 300 W. By comparison, standard kitchen cooking plates typically operate at 1,000 W or more. This leads to lower levels of performance, longer cooking times and potential customer dissatisfaction.

A number of comments arise with this approach:

***Limited Urban Application***

In cities with high housing density, especially where families live in high-rise buildings, the opportunity to deploy solar PV is highly constrained. With limited or no access to roof space, these systems cannot realistically be deployed.

***System Costs***

According to the literature, a direct DC 500 W PV system (including an electric pressure cooker, small induction hob, controls, insulation materials, etc.) costs in the region £300 or $360 per household.

By contrast, other clean cooking technologies with subsidies fall in the range of $30-50 per unit. An initiative targeting one million households would therefore cost 030£ million for the PV systems alone. For rural poor households—the main focus of such systems—these costs are prohibitive.

***Hours of Usage***

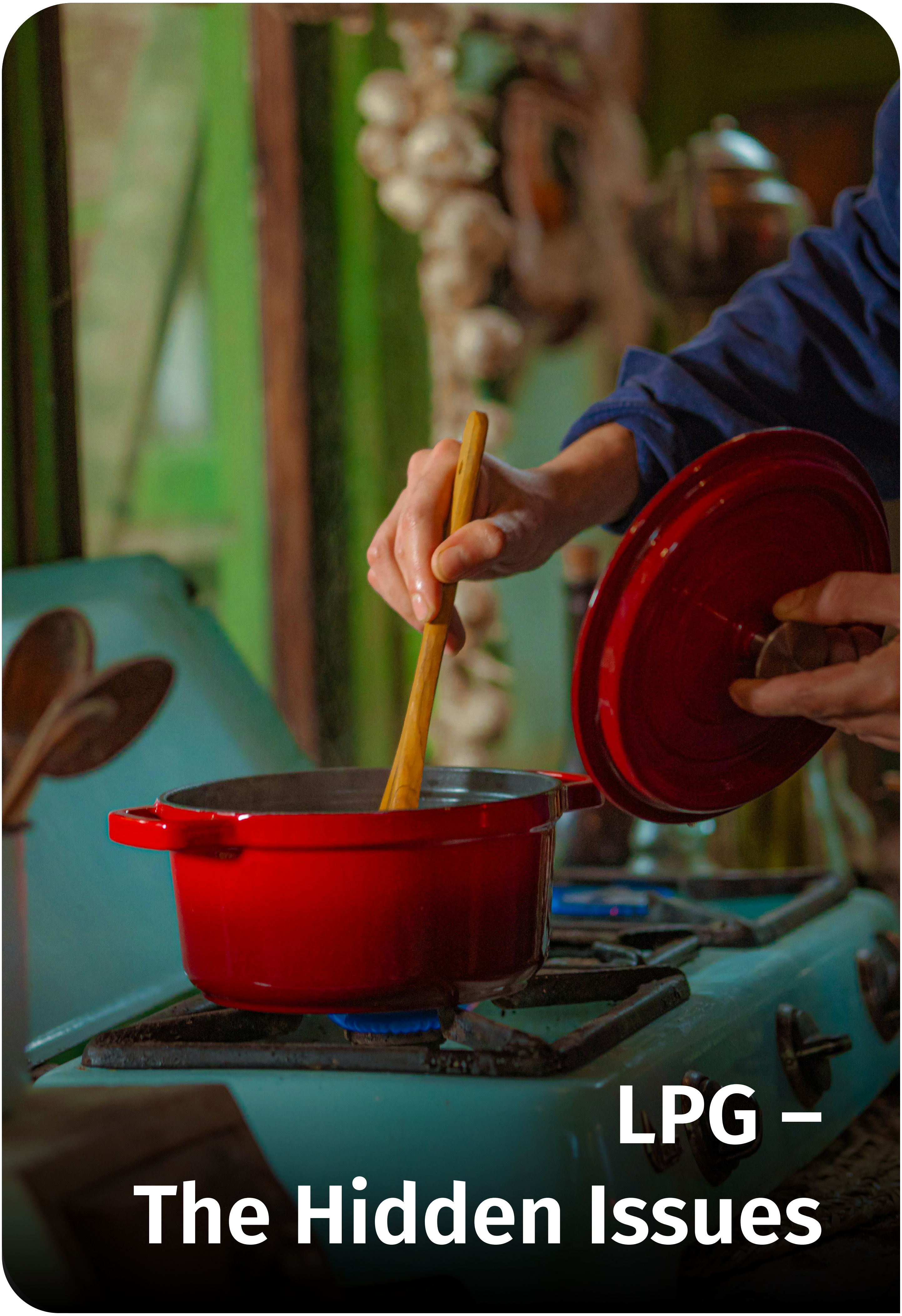
The daily production profile of solar PV, combined with the absence of battery storage for later electrical use (due to prohibitive costs), imposes a significant constraint. Households requiring hot water or food preparation in the morning and evening, aligned with typical daily routines, would be unable to rely on these systems.

***Weather Impact***

Inclement weather has a direct impact on system usage, as clouds cover and rainfall can lower solar PV output below the level required for cooking. In addition, households must be available to shift cooking times to match variable weather conditions.

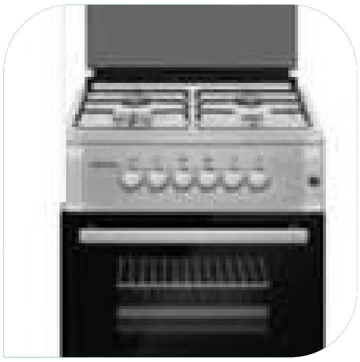
***Cooking Duration***

With 300 W solar PV sourced cooking appliances, boiling 2 litres of water would take approximately 38 minutes (excluding any losses). This is far longer than the time required using electricity, LPG, ethanol, or other cooking fuels.



# LPG – The Hidden Issues

For years, LPG-based cooking has been viewed as a quick fix to the challenge of traditional cooking (charcoal, wood). Globally, the WLPGA (World LPG Association) has launched a programme targeting 2 billion households in developing nations, forming the primary thrust of many Governments' clean cooking strategies. Tanzania is a good example of this focus, with VAT exemptions and recent stove subsidies.



At the household level, LPG offers a clean and modern cooking solution, including:

- Low levels of indoor air pollution.
- Widespread familiarity with the technology.
- Low-costs appliances, with cooker-on-cylinder options available.
- An existing distribution industry that makes refills accessible.

While this route offers Governments an easy pathway to clean cooking, this section sets out the major risks and lost opportunities associated with such an approach.

## LPG Contextual Information

- The basic constituents of LPG are propane and butane, which are gasses at room temperature and pressure. They are compressed into liquid form and stored in pressure vessels (cylinders). During use, the valve or regulator allows the liquid to vaporise back into gas at a controlled rate for burning in the stove.
- LPG is a by-product of the oil and gas industry and, as such, is a non-renewable source of heat. During crude oil cracking in refineries, between 2-4 per cent of the barrel is released as propane/butane. In addition, during the "cleaning" of raw natural gas, propane/butane and other heavier molecules are removed to produce pure methane.
- Globally, this by-product has been turned into a high-value fuel. With the expansion of natural gas networks, the historical markets for LPG have been eroded. Hence, the drive within the LPG industry is to promote the fuel around the world, particularly for automotive use and clean cooking in developing markets.

- The supply of LPG should be understood as a straightforward commercial operation: the fuel is purchased in bulk, shipped, distributed, and sold at a margin. The industry has operated for many years and is constantly seeking new markets.
- Company investments include the purchase of delivery cylinders, which remain in the property of the distribution companies and not the householders. The management, exchange, and control of cylinders is an established commercial activity carried out by distributors.

## LPG is a Fossil Fuel, Not Renewable

LPG, being a hydrocarbon, is a non-renewable source of energy whose use inevitably leads to increased levels of greenhouse gas (GHG) emissions. While it is often promoted as a by-product in the oil industry, this should not justify its use as a primary cooking fuel. Instead, the oil industry should prioritise redirecting LPG into applications with minimal $CO_2$ residue, such as feedstock for chemical production.

From a household perspective, LPG is undeniably effective, offering low levels of indoor air pollution and benefitting from an existing delivery infrastructure. However, countries must remain conscious that a shift to LPG-based cooking perpetuates reliance on a fossil fuel and fails to deal with GHG emissions. That said, switching from wood and charcoal to LPG does provide major benefits, notably lowering deforestation pressures.

## Company Complexities and Impacts on Household Access

The LPG distribution industry has been around for many years and is a stable/existing partner for the delivery of an alternative cooking fuel, often with international banking/ownership (Oryx, etc.) to provide working capital to fund expansion. However, a rapid increase in an LPG cooking market will require the following matters to be managed:

- **Cylinder costs –** Each household will need an LPG cylinder for use. The cost of cylinders is primarily borne by the LPG industry, which translates into the need for major capital investment by the companies. This investment, along with the cost of cylinder refurbishment at regular intervals, has to be recovered by the industry over the life of the cylinders. A direct consequence of this is the industry's resistance to any form of regulation or price controls.
- **Upfront customer payments –** A deposit or partial payment for the cylinder cost is still required from the customer, which forms part of the upfront cost of the LPG cooking option.
- **Cylinder exchange model –** Two LPG industry models of cylinder exchange are found:
  - Like-for-like exchanges, where only similar branded cylinders are exchanged. This limits the household's freedom to shop around for cheaper LPG. This approach is employed in Tanzania, for example.
  - Behind-the-scenes exchangers, where different branded cylinders are exchanged, allowing customers

to shop around for the cheapest refill even with a different brand. To keep the market functioning, LPG companies then exchange these cylinders behind the scenes. South Africa is an example of this approach.

- **Rogue refillers –** Given the lucrative financial opportunity for sellers of LPG refills, the practice of "rogue cylinder refillers" can emerge. Here, independents refill branded (owned by other company) cylinders for resale without investing in the cylinders or participating in their regular refurbishment. This practice needs to be declared illegal, with associated penalties.

Overall, the major players in the LPG industry will fund part of the market development costs; however, they will also expect a range of supporting regulations, industry rules, and protections as part of the development. ***While Governments will need to support/regulate the industry, the household benefit is an industry-subsidised cooking unit (cylinder + stove). The risk is the lock-in of households to one source of gas.***

## Cylinder Size and Refill Costs

Due to the economics of cylinder filling and distribution, company-owned LPG cylinders typically start at around 4 kg of gas. This substantial volume of LPG represents between 60-70 per cent of a household's monthly cooking needs. The downside for households is the high upfront cost: around $7 for a 4 kg cylinder or $10 for a 6 kg cylinder, payable as a single payment.

Households often need to purchase cooking fuel for 1-2 days at a time, not 20 days as is the case with LPG. Trials of dispensing valves connected to cylinders and real-time banking payments have proved prohibitively expensive. In addition, small-cylinder operations are being trialled, but again the economics are not proven given the higher handling costs per kg of gas sold.

*Decision makers need to appreciate the high barrier to purchasing LPG refills, which limits the use of LPG to higher-income sections of the population.*

## LPG Importation and Price Fluctuation Risks

With the need for LPG importation in most countries, the switch to LPG cooking depends on pricing, which is directly linked to crude oil prices.

- A continued upward trend in LPG prices as crude oil prices rise over time, coupled with short-term price fluctuations in line with crude oil volatility.
- Being a fully imported product in most developing countries, any exchange rate changes will also impact the price.

*Overall, all households that switch to LPG-based cooking will be exposed to crude oil price increases and exchange rate fluctuation risks.*

## Supply Continuity Risks and Strategic Stock

Being an imported product in many countries seeking to transition from traditional cooking, interruptions to the offloading of LPG can significantly affect local supply. Any LPG shortages following a large-scale move to LPG cooking would have a major impact on households. Implications of importation risk are outlined below:

- In-country stock levels – LPG stocks should be roughly equivalent to two months of supply, with some of the product stored in replacement cylinders and at local filling plants. Higher up the supply chain, bulk storage of at least one month's LPG stock is necessary.
- High cost of storage – LPG storage tanks are high-pressure vessels specifically designed for the application, unlike petrol or diesel storage, which does not require pressurised containment. This makes LPG storage very expensive, and the industry often seeks to minimise investment in storage, creating supply risks. For example, in South Africa, only 3-4 days of strategic LPG stock are maintained, far below safe levels.

- Practical example – Consider a rollout to 1,000,000 households, with typical LPG usage of at least 5 kg/month. A one-month bulk tank strategic stock would require 5,000 tons (10,000 $m^3$). The cost of such a tank farm would be at least $2 million, in addition to $5 million for the fuel itself. As the LPG market grows, the strategic stock volume will increase, and the industry must be prepared to invest accordingly.

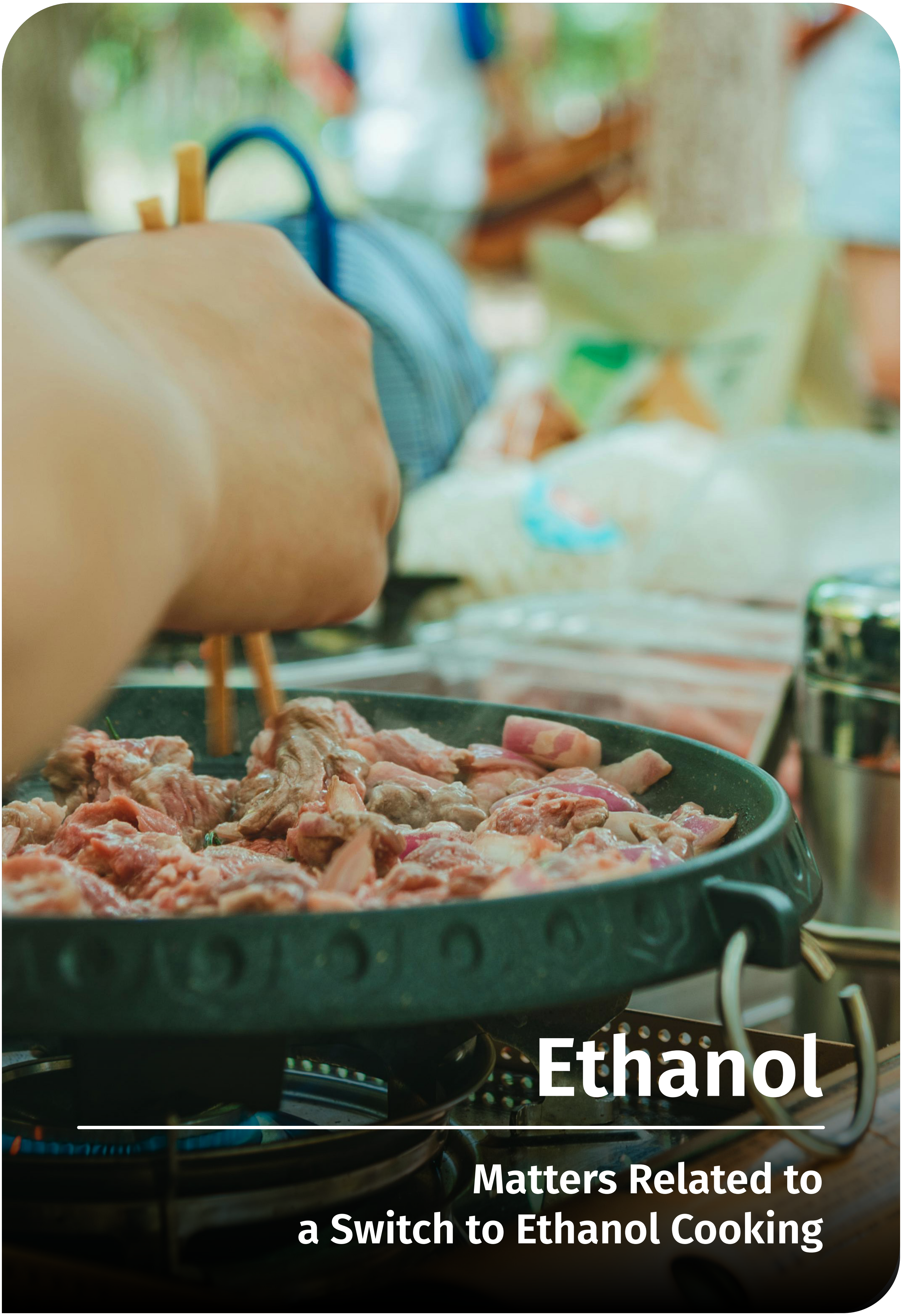
***For any major-scale LPG cooking programme, Governments will need to legislate to ensure that in-country strategic stocks are maintained at levels sufficient to prevent shortages, despite the significant associated costs.*** Failure to manage this matter could lead to major household supply disruptions if the supply chain is interrupted.

## Lost Economic Opportunity

Perhaps the biggest issue associated with imported LPG for cooking is the very low economic multiplier or the lost economic opportunity for in-country fuel production, for the following reasons:

- When LPG is simply imported, it generates very little added value through handling, bottling, and sale to the end user, resulting in minimal economic impact.
- Most major LPG importers and distributors are internationally owned, leading to repatriation of profits abroad.

*Adopting LPG as the primary cooking fuel will therefore result in low economic multipliers, a drain on foreign exchange reserves, and limited employment generation in comparison to the wood and charcoal industries being replaced.*



# Ethanol

## Matters Related to a Switch to Ethanol Cooking

From the early days of trials and use in refugee camps through to a functioning market of between 1-2 million households, many now relay on bioethanol-based cooking. The root of ethanol cooking lies in the US recreational market, ranging from yachts to camper vans.



A competitive market offer—combining efficiency, convenience, cleanliness, and affordability—is essential to ensure that households are willing to invest in and switch to ethanol cooking.

The following stove features have been identified as important in encouraging the switch:

- Burning powerfully (>1.4 kW), fully comparable with modern LPG or electric stoves.
- Burning cleanly, leading to minimal indoor air pollution when used inside houses.
- Appealing and attractive design, available as either single or double burner stoves.
- Easy and safe operation, with simple filling and lighting, no spillage, and no danger of pressurization or explosion.
- Guaranteeing practical, safe, and secure fuel storage.
- This type of ethanol stove has been extensively tested under ISO standards and achieves a strong Tier 5 score for the primary measures of thermal efficiency, carbon monoxide per energy delivered, particulate matter (PM 2.5) per energy delivered, and safety.

## What is the Bioethanol Cooking Fuel?

Ethanol used as a cooking fuel needs to be anhydrous ethanol (95 percent ethanol, 5 percent water), which is produced in ethanol distilleries. In the distillation process, the most appropriate fraction is called *rectified alcohol*, with heavier carbon impurities (higher alcohols) removed to ensure a clean burn. Of note, the highest quality ethanol (*extra neutral alcohol*) requires further processing and is used as food grade for beverages.

Lower quality ethanol with higher levels of impurity can be used, but requires the addition of around 15 per cent methanol to achieve a clean burn. Both ethanol and methanol are low in carbon, high in hydrogen, and contain oxygen in their molecules, which is why they burn so cleanly. Rectified ethanol produces a clear, blue flame with no soot. The lower the carbon content in any fuel, the cleaner and easier it burns.

Countries need to adopt ethanol fuel standards and be able to monitor the quality of supplies.

## Stove Safety

The true miracle of these stoves is the adsorptive fuel containment system. The container (or canister) includes a densely packed fibre material that provides a vast "wetting" area, to which the alcohol fuel adheres. The viscosity and surface tension of ethanol are low, causing it to coat the surface of the fibre in the canister. Provided the canister is not overfilled, no droplets form inside. Thus, if the canister is inverted, the fuel will not spill out and there will be no fire spread if the stove is knocked over.

Since the canister mouth is not pressure-sealed, the canister remains at atmospheric pressure. When the stove's regulator plate is opened, alcohol fuel readily evaporates from the canister into the combustion chimney, where it burns not as a liquid fuel but as a gas. With air mixing in the chimney, efficient combustion is achieved.

**Overall, with Governments adopting stove standards, the fuel can be included in the mix of clean cooking options without safety concerns.** Tanzania, Kenya, and others already have such standards in place.

## Ease of Fuel Delivery and Barrier to Entry

With no fuel pressurisation needed during transportation, ethanol can be delivered in 1, 2, or 5litre bottles similar to cooking oil. The fuel is then poured by households into the stove for use. Furthermore, this feature lowers the barrier to market entry for distributors, as only fuel mixing and bottle filling activities are needed.

***For Governments, this low barrier to entry for distributors is advantageous, as a competitive market can be readily developed.*** Of course, the sector needs to be regulated in terms of fuel standards, delivered fuel quality, and handling practices.

## Sourcing of Bioethanol

Ethanol is produced from agricultural sources; hence the fuel is fully renewable, depends on feedstock choice and process efficiency, leading to the term *bioethanol*. In the production process there are two pathways: from a sugar source, such as molasses, or from a starch source, such as grain. In the case of a starch source, the grain has to be pre-processed into sugar before use. The sugar is then fed to microbes or yeasts, which convert it into alcohol. At this stage, the ethanol concentration is low (10-14 per cent); a further distillation process is needed to raise the concentration to 95 per cent.

Sources of sugar generally come from agricultural waste, including molasses from the sugar industry, sisal bolls or centres that contain sugar at the end of their useful life, cashew apples, etc. Sources of starch need not be limited to traditional maize grains, but can include red sorghum, triticale, and others. The sources will vary from region to region.

*Governments can identify potential sources available in the country, both waste and cultivated, and extrapolate volumes for a clean cooking programme.*

## Dealing with Land and Food Security Risks

Food security and land use are often raised as concerns when discussing biofuels; however, in the case of ethanol for household cooking, these issues are limited and manageable. Ethanol used for cooking does not need to come from staple food crops grown on prime agricultural land. In many successful programs across Africa and Latin America, ethanol production has relied on feedstocks such as molasses (a by-product of sugar production), surplus or non-food grade grains, and other residues that would otherwise go unused. This means ethanol supply chains can be built on agricultural by-products, reducing waste and creating additional income streams for farmers, rather than competing with food production.

From a land-use perspective, ethanol cooking fuel actually reduces strain on ecosystems rather than worsening it. The main driver of unsustainable land use in many countries is not ethanol production, but the harvesting of firewood and charcoal for cooking, which causes large-scale deforestation, soil degradation, and reduced agricultural productivity.

By displacing charcoal with ethanol, households contribute to protecting arable land, conserving forests, and maintaining ecosystem services that underpin long-term food security. Ethanol supply systems can be scaled with careful policy to prioritize by-products and marginal lands, while leaving fertile cropland for food. Thereby, ethanol for clean cooking represents a land-efficient, food-secure, and climate-aligned pathway for modernizing household energy.

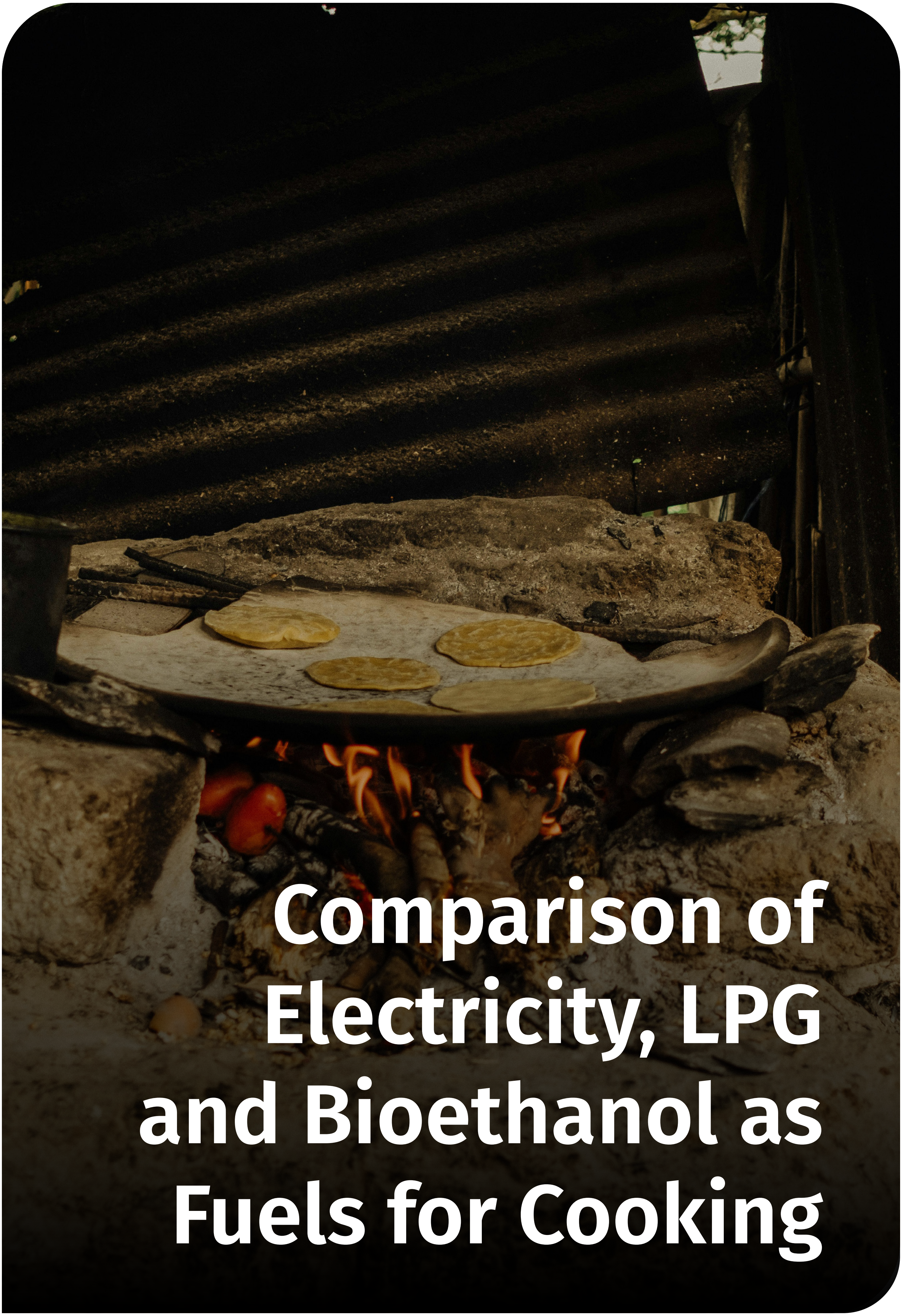
## Localised Ethanol Production – A Major Economic Opportunity

Perhaps the greatest advantage of bioethanol cooking is that the fuel can be produced locally, reducing the need for imports and ensuring self-sufficiency. This creates a major economic opportunity, as the industry developed for ethanol production through to downstream distribution feeds directly into the local economy. In other words, all economic activity required to supply cooking fuel to meet household needs remains within the country. Of course, while ethanol cooking markets are still developing, imported fuel can work hand in hand with local production.

## Strategic Stocks

Ethanol production can be seasonal, but continuity of supply can be guaranteed through storage in low-cost tanks.

*The industry can be regulated to ensure that at least two months of strategic stock is retained, thereby preventing shortages.*



# Comparison of Electricity, LPG and Bioethanol as Fuels for Cooking

| Characteristic | Bioethanol Cooking | LPG Cooking | Electric Cooking |
|---|---|---|---|
| *The technology* |  |  |  |
| *Customer knowledge of the cooking technology* | Ethanol cooking is a new concept for customers, which increases the efforts needed to encourage fuel switching, such as demonstrations and other promotional activities. | An old established technology, with most households having some level of knowledge. However, this is offset by a fear of explosion, which is largely unfounded during normal use. | In developing markets, electric cooking is not widely known, and the technologies being promoted (e.g., pressure cookers and induction stoves) are new to many households. |
| *Is the cooking experience modern, clean and effective?* | Whilst ethanol stoves are still early in their development pathway, they already offer users a modern, controllable, clean, and effective cooking experience. Further development will be driven by the introduction of higher-end stoves. | Used by hundreds of millions of households around the world, including top chefs. LPG cooking can certainly be classed as modern, clean, and effective. | Perhaps the highest level of modern cooking, with the controllability of induction hobs and the effectiveness of pressure cookers for ingredients requiring long cooking cycles. |

| Characteristic | Bioethanol Cooking | LPG Cooking | Electric Cooking |
|---|---|---|---|
| *Stove HAP ratings* | Tier 4/5 | Tier 4/5 | Tier 5 |
| *Stove costs and complexities* | Basic cost of single-plate stove is around $30, with no cost or deposit associated with fuel purchase. Fuel is supplied in either discardable or returnable plastic bottles. | A basic stove for the top of a cylinder costs $12, but the deposit on an industry-subsidised cylinder is a further $10. Cylinders are simply exchanged for refills. | Pressure cookers or induction hobs cost around $50, with the cost of connection already covered if the household has electricity available. |
| *Running costs and price risks (Tanzanian example: note these are place and fuel price-specific)* | $1.25/meal<br>In-country production implies only inflationary increases. | $0.87/meal<br>Being an imported hydrocarbon-based fuel, prices will escalate with crude oil and vary with exchange rate fluctuations. | $0.50/meal<br>While produced in-country, significant upward price pressures are expected due to additional generation capacity investments required. |
| *Fuel access* | Ethanol, being a new entrant, faces challenges in immediate availability. Economics of scale require an area-by-area approach, with fuel outlets matching stove sales. Expanding stove distribution to underserved areas can create negative perceptions if fuel is not yet available. | LPG is already available in most countries. However, a large-scale shift in household cooking will require increased availability of exchange cylinders, including both the number of cylinders and access to suppliers. | In developing countries, grid access is often limited, especially in rural areas. Reliable 24/7 electricity is a prerequisite for any cooking programme. |

| Characteristic | Bioethanol Cooking | LPG Cooking | Electric Cooking |
|---|---|---|---|
| *Upstream fuel supply matters* | Ethanol is available on a small scale from existing producers. As bioethanol cooking markets grow, new production plants will be needed, linked to agricultural sugar waste and specifically grown starch crops.<br>Additionally, new distribution industries must be developed for fuel preparation, bottling, and retail. | LPG is already imported and distributed, but a switch to LPG cooking will require major investments at a few levels: strategic stocks in pressure vessels, sophisticated cylinder bottling plants, and the cylinders themselves. | Each new electric stove requires additional generation capacity (e.g. 0.1 kW). The scale and cost of renewable electricity production to support these new loads is massive. Electric cooking based on solar PV or intermittent wind without storage planning is impractical due to mismatched load profiles. |
| *Is the fuel obtained from a renewable source?* | Yes. Using agricultural by-products and renewable sources, the $CO_2$ emitted at point of use is largely offset by the plant lifecycle. | No. All LPG is sourced from hydrocarbons, leading directly to $CO_2$ emissions and contributing to global warming. | Depends on the renewable share of the grid. Currently, solar and wind levels are low in most developing countries, meaning electricity is largely non-renewable. Switching to electric cooking before modern renewables make up at least 75 per cent of the energy mix (kWh) could double household carbon footprints. |

| Characteristic | Bioethanol Cooking | LPG Cooking | Electric Cooking |
|---|---|---|---|
| *Strategic stocks for continuity of supply* | Ethanol production can be seasonal; distributors need at least two months of storage. Fuel can be stored in standard, non-pressurised tanks. | As LPG is imported, maintaining in-country strategic stocks is critical (at least 2 months). Storage requires major infrastructure and high-pressure vessels, making it costly. | Electricity cannot be stored by households. Grid reliability issues and lack of storage for morning and evening peaks can lead to interruptions in supply. |
| *Localisation and economic multiplier effects* | A major economic opportunity exists: agricultural activities, ethanol production, and distribution remain in-country, generating jobs and financial multipliers. | Minimal economic multiplier: funds from LPG sales largely circulate through the distributor and leave the country. This in turn drains foreign exchange reserves. | Limited local benefits, particularly with capital-intensive grid power. Renewable generation may create few jobs, and using electricity for cooking has lower economic impact than developing a broader industrial base. |

*Prices of fuels and equipment used in the brief are for illustrative purposes from fixed dates and places. Please note such prices will vary across countries and applications, and may shift over time.*

# Conclusions

In developing nations where modern energy-based cooking is unavailable for many households, there are only three realistic potential sources of fuel to provide modern cooking solutions: electricity, LPG, and bioethanol. Governments need to recognize this reality and plan accordingly before aligning SE4ALL and other clean cooking programmes with their mix of fuels and appliances.

The scale of need—approximately 400 million households—requires a monumental effort, equivalent to switching around 100,000 homes per working day over 15 years. Choosing only one fuel cannot be the solution; all three fuels need to be embraced. Countries must determine the appropriate target share for each fuel in line with national dynamics; including:

- Ethanol feedstock availability to support local production.
- Electricity availability now and projected in the future.
- The need for LPG importation and the potential impact on balance of payments.

Importantly, countries must also consider the constraints and challenges linked to each fuel option:

- **Electricity:** grid infrastructure, household connection rates, existing generation mix, generation investment plans, peak load growth (morning and evening) and financial viability.
- **LPG:** dependence on imports, balance of payments impact, crude oil price and exchange rate volatility, requirements for strategic stock in pressure vessels, and industry investment in cylinder filling and distribution.
- **Ethanol:** customer awareness, development of new domestic industry, and establishment of a full supply chain.

Unequivocally, bioethanol must be considered one of the key options for clean cooking.

Successful implementation will depend on credible delivery plans, underpinned by market modelling to ensure both household affordability and alignment with customer preferences.

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